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LAVA FLOWS OF MOUNT ROUSE, WESTERN VICTORIA

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Abstract: Mount Rouse, an extinct volcano located immediately south of Penshurst in Western Victoria, was a source for copious lava flows which followed several pre-existing valleys and reached the coast 60 km to the south. Many typical features of drainage modification are associated with the lava flows. Stony rises are widespread and interpreted to mean that a lava tube mechanism was in operation when the lava was flowing, and indeed was necessary to produce such long flows. If this is so, eruption of all lava occurred in a very short time. A new date for the volcano is 1.8 m.y., which is inconsistent with ages of about 0.3 m.y. reported from basalts near Port Fairy. The Mt Rouse flows serve as a useful marker in distinguishing Pleistocene from older volcanoes in the region. The Mount Rouse basalt has suffered very limited weathering: the basalt of the nearby Mount Hamilton land-system, which is about twice as old, is very much more weathered.

The Western Plains of Victoria contain many volcanoes, and are largely covered by a veneer of basalt. There are about 200 points of eruption on the plains, and they range in age from several million years old to about 15 000 years for Tower Hill (P. Kershaw, pers. comm.). The area is a distinct volcanic province characterised by areal or polyorifice volcanicity. The volcanoes are numerous but small, and each was active only once, and then for a short time. This contrasts with the central volcanic type of eruption, in which eruption may continue at the same site for millions of years. The general sequence of eruption at volcanic centres of the Western Plains of Victoria was first a highly explosive eruption to produce a maar, then effusion of very fluid lava which flowed down valleys and spread over plains if sufficiently voluminous, and finally the build-up of a scoria cone. Some points of eruption do not show all three phases, and occasionally other landforms (such as lava cones) may be built.

Some of the volcanoes and flows have been dated by radiometric methods. Relative dates for some have been deduced by examining the degree of weathering and erosion, and the relative disruption of drainage patterns. In the far west, for instance, Mt Clay and Mt Vandyk are very old and deeply weathered with very few rock outcrops. Mt Eccles, on the other hand, only about 20 000 years old (Ollier 1981), has hardly any weathering and its original flow structures are preserved almost intact. In between come many volcanoes and flows with intermediate degrees of weathering and erosion. Gibbons and Gill (1964) postulated a relative sequence of groups of volcanoes based on the nature of the volcanic landscape, essentially the depth of soil and the preservation of stony rises. The same technique is described further by Gibbons and Downes (1964).

This paper is about the lava flows of Mount Rouse, which have intermediate weathering and erosion, and are part of the Girringurrup land-system of Gibbons and Gill. Mt Rouse is located just south of Penshurst and about 10 km east of Hamilton (Hamilton 1: 100 000 map, grid reference 142062). The scoria cone is about 100 m above the surroundings, and has an elevation of 370 m above sea level. Mount Rouse is a composite volcano, mainly built of scoria but with a few inter-bedded flows. To the south of the scoria cone lies a lower, well-defined, basalt-rimmed crater [Fig. 4, also figured in Ollier & Joyce (1964)]. Lava from Mount Rouse occurs in two large patches, connected by narrow lava-filled channels. One large patch lies immediately south of the volcanic cone; the other is farther to the south and reaches the coast (Fig. 1).

LAVA FLOWS

Only a small amount of lava flowed north of Mount Rouse, but one patch extended about 4 km to the northwest and filled a valley head. A small lateral stream called Penshurst Creek on Fig. 2 flows along the northern edge of the lava lobe, away from the volcano and into Buckley Swamp. Buckley Swamp was created when the younger Mount Napier volcano blocked the drainage of this area. Before that, Penshurst Creek was probably a tributary to a river that flowed under the site of Mount Napier to the Harman Valley, but it may alternatively have been an upstream continuation of Muddy Creek.

Along the Eumerella River, which marks the northwest edge of the Mount Rouse lava flows, the lava appears to have simply banked up against old topography, for the pre-basaltic drainage was largely to the south and there were no convenient valleys to follow to the west.

Due southeast of the eruption point, a lava flow followed the valley of Spring Creek, and south of this, two other narrow strips of lava followed Whitehead Creek, and Whitehead South Creek.

The northern mass of lava drained south through two main valleys, now occupied mainly by Back Creek and the Moyne River. The Back Creek lava flow route is the simplest. The flow becomes more and more confined until, at its narrowest, it is only 200 m wide. The flow is less than 1 km wide over a distance of more than 5 km and then spreads out, originally overtopping low

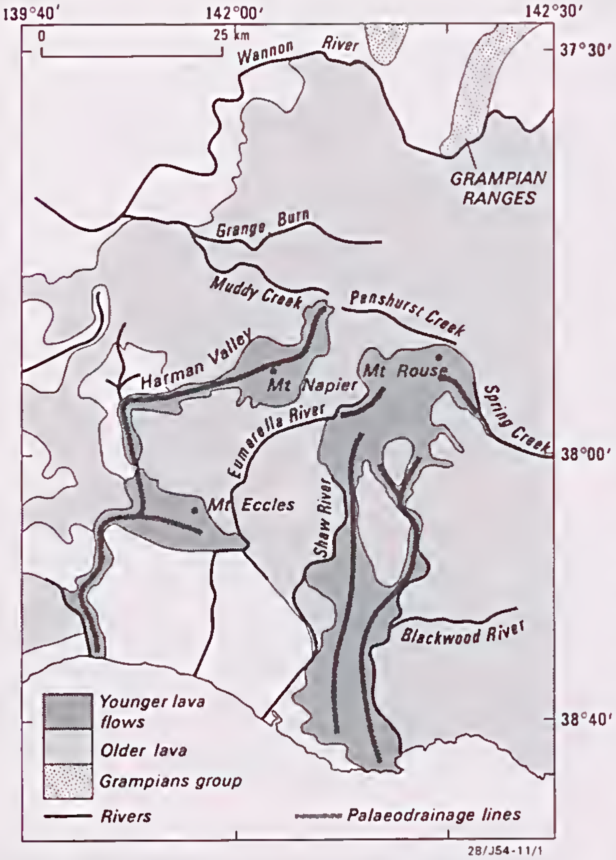

Fig. 1—The geomorphic setting of the Mount Rouse lava flow.

divides, and follows several different creeks. Some interfluve areas are now "islands" of bedrock surrounded by lava flows (steptoes).

The Moyne River lava flow route is more complex, with two lava flows, labelled the Wandilla and the Glenlevitt, surrounding the Moorilah Steptoe (Fig. 5) and then uniting as the Moyne River lava flow. Over a distance of 6 km this flow is less than 1 km wide, but then it widens out and joins the Back Creek flow. The Coomealla Steptoe, 19 km long, was formed between the two flows. The united lava flow then continues south, getting wider, until at the coast its width is about 14 km.

DRAINAGE MODIFICATIONS

The Rouse flow provides splendid examples of drainage modifications such as diversion, lateral streams and twin lateral streams. The Eumerella is a fine example of a lateral stream, following the edge of the lava for about 15 km, not including the small meanders. The stream then leaves the lava edge, possibly following its pre-lava course. Twin lateral streams can be found at all scales (Fig. 2). At a large scale, the Shaw River and the Moyne River are lateral streams on the main Rouse flow where it enters the sea, though each is in fact more complex in detail. On a medium scale, Back Creek and Shaw River North are good examples, and on a small scale Whitehead Creek is excellent, with two streams flowing parallel for 7 km on opposite sides of a lava flow less than 200 m wide.

Successive diversion is shown by the sequence starting with the Shaw River North, which, after being a lateral stream, is diverted into the Carmichael, which in turn is diverted into the Kangaroo Creek, and finally becomes the Shaw River Central (Fig. 2).

A few rivers manage to cross lava flows from one side to the other: the Moyne River does it several times.

The inliers (steptoes) are also commonly bounded by streams, such as the Back Creek and the Moyne River bounding the Coomealla Steptoe, and the twin streams bounding the Moorilah Steptoe (Fig. 5). Even quite tiny steptoes are often bounded by streams on at least one side.

PALAEOGEOGRAPHY

Evidently the flows from Mount Rouse were poured over an initially flat topography with narrow, little-incised streams, and a generally southern slope so that most lava flowed in that direction. By interpolating streams between twin laterals; locating old streams where the lava has a lobate outline; and, by making reasonable guesses where lava has overtopped divides, it is possible to make a reasonable reconstruction of the pre-basaltic drainage pattern. This pattern is shown in Fig. 3 and is essentially a simple dendritic pattern showing southward drainage from a divide in the vicinity of the present Mount Rouse.

Even this old drainage was on a landscape modified by earlier lava flows. A large lava flow of unknown source had disrupted earlier drainage from the north, and the River Wannon is a lateral stream with an east-west course along the northern edge of this lava plain. The younger Mount Napier eruption blocked drainage going southwest, forming Buckleys swamp, but not apparently diverting any water into the catchment of the streams associated with the Mount Rouse lava flows, for there is a low watershed between the Buckleys Swamp-Weerangourt drainage and the Eumerella drainage (Fig. 2). Nevertheless it seems that the Mount Rouse eruption occurred on relatively high country between the drainage going to the Wannon, to the proto-Eumerella, to Spring Creek, and south to the proto-Shaw and proto-Moyne (Fig. 1). It is not yet clear why the Blackwood River has an east-west course in this region of generally north-south drainage, but in any case, the lava did not follow it.

SURFACE FEATURES OF THE LAVA PLAIN

Almost everywhere the surfaces of the Mount Rouse flows are distinguished by stony rises, a term given to rough, rolling topography with mounds or ridges and intervening depressions. The difference in height between the hollows and the rises is usually about 3 m but can be up to 10 m, and the distance between adjacent rises is usually 15-30 m but may be over 100 m.

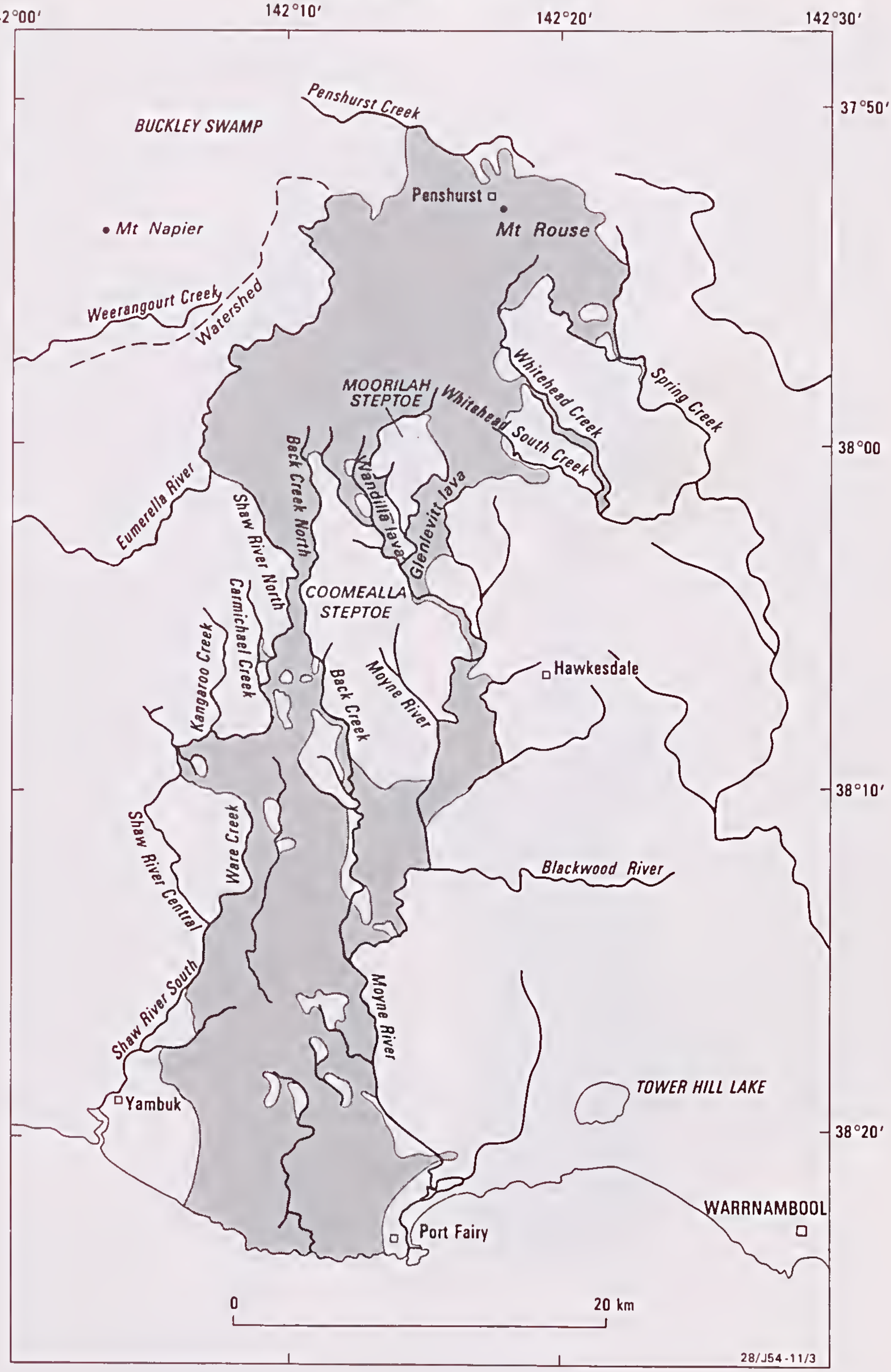

Fig. 2—The Mount Rouse lava flows and associated drainage.

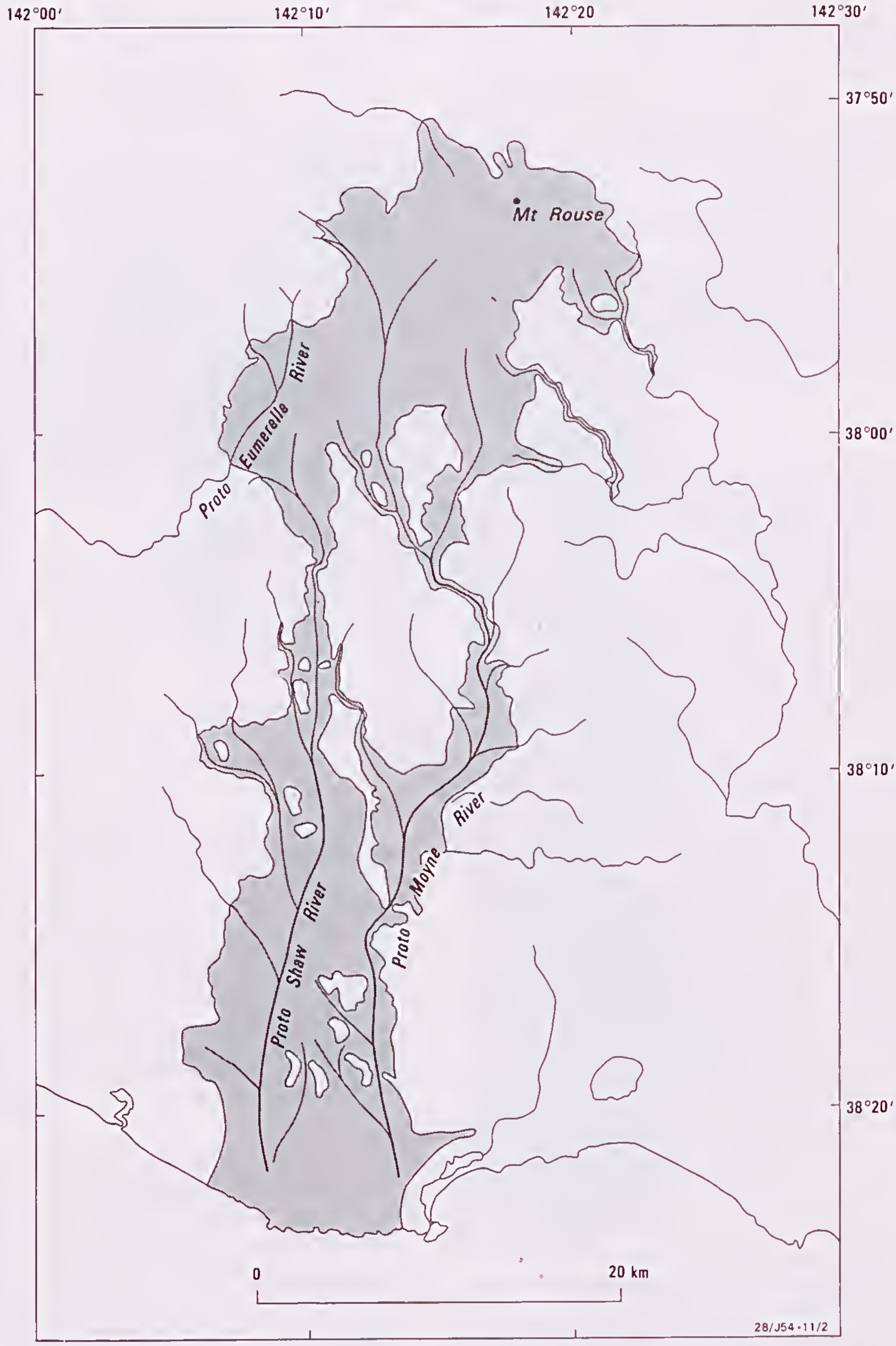

Fig. 3—The drainage of the area between Penshurst and the coast as it was immediately before the eruption of Mount Rouse.

The surface often consists of short columns, and the jointing suggests that the surface was once flat, with joints perpendicular to it, and that the carapace was draped over the rises as lava was withdrawn beneath the depressions. The pattern of mounds and depressions suggests that hot liquid lava flowed in a braided network beneath a crust of cold, fairly rigid lava, which was still sufficiently plastic to bend when lava was eventually withdrawn from the tubes.

WEATHERING AND SOIL

Gibbons and Downes (1964) describe the topography and soils of the Mount Rouse flow as part of the Girringurrup Land-system. On the rises are reddish chocolate soils, with abundant boulders and "floaters" of basalt. On the sides of the rises the soil becomes darker, and in the swales are black cracking clays, sometimes with carbonate. Gley soils are present in the wetter depressions. The soils have a relatively high base exchange capacity.

The country bounding the Rouse flow consists of what Gibbons and Downes mapped as the Greenhills Land-unit of the Hamilton Land-system, which is formed on basalt. The Land-system has flat topography, with no trace of stony rises although it is undulating in parts. It is weathered to a depth of up to 10 m and sometimes bauxitised. The weathered profile has an upper, strongly reddened and friable zone, an intermediate mottled zone, and a lower pallid zone above the altered rock. No ferricrete or other indurated zones are present. On the kaolinitic zone soils are either krasnozems or red solodic soils. Middle and lower slopes have brown solodic soils, and on the lowest sites are limited areas of prairie soils or chernozems.

THE AGE OF THE LAVA FLOWS

The age of the Mount Rouse flow has been estimated from the degree of erosion, weathering and soil formation. Although the basalt is weathered to the stage of spheroidal weathering, the soils still have a high content of exchangeable cations compared with those of the older flows in the area, which have been weathered to the kaolinitic stage. The stony rises are well preserved and the drainage little incised. In brief, the physiographic evidence suggests a young age. Gibbons and Gill (1964) thought that the flow might be within the range suitable for radio-carbon dating, which seemed a reasonable idea at the time, and suggested a Holocene age.

Jackson *et al.* (1972) suggested that the Girringurrup Land-system (which includes the Mount Rouse flow) is less than 100 000 years old, the Dunkeld Land-system about 500 000 years, the Cobbobbonnee about 1 000 000 and the Hamilton about 4 000 000. The rocks of the Mount Rouse flow are generally unsuitable for dating by the potassium-argon method, because they are both vesicular and weathered. However, McDougall and Gill (1975) dated the Woodbine flow near Port Fairy, which seems to be part of the Rouse flow, and basalt from west of the Moyne River about 10 km north of Port Fairy. They reported the following ages:

PF 1 (Cape Reaumur)	0.312 ± 0.005 m.y. (0.320 m.y.)
PF 2 (Port Fairy)	0.301 ± 0.008 m.y. (0.309 m.y.)
PF 10 (N of Port Fairy)	
	0.404 ± 0.017 m.y. (0.415 m.y.)
	0.438 ± 0.007 m.y. (0.450 m.y.)

(The figures in parentheses are ages calculated from new decay constants.)

The internal consistency of these dates suggests reliability. McDougall and Gill maintain that it is unlikely that the ages are too old, but do not discuss the possibility of them being too young. The inference that they have flows of at least two different ages is not consistent with the suggestion in the present paper that all the lava between Mount Rouse and the coast belongs to one flow.

The pyroclastics of the scoria cone at Mount Rouse are unsuitable for isotopic dating, but a single, fresh looking lava flow was found interbedded with the scoria, and was sampled for dating. This rock is a fine grained, slightly vesicular basalt containing 5-7% of small (generally <0.3mm) fresh olivine phenocrysts set in a fine-grained groundmass which exhibits a strong fluidal alignment of plagioclase laths. The laths, up to 0.2 mm in length and generally less than 0.02 mm wide, comprise about 30% of the groundmass. They are very fresh and probably of andesine composition. The remainder of the groundmass is very fine grained and contains abundant iron oxide granules (about 0.005 mm), fine pyroxenes and small clear patches of feldspar. The groundmass is holocrystalline and although not perfectly transparent (because of the fine grain size) it appears to be fresh and unaltered. The rock seems therefore to be suitable for total rock potassium-argon dating. It is unfortunate that no other sample has been found yet to provide another date for confirmation, so

TABLE 1

K-Ar ANALYSES OF LAVA FLOW FROM SCORIA CONE AT MT ROUSE

Sample	% K	$^{40}Ar^*$ ($\times 10^{-11}$ moles/g)	$^{40}Ar^*/^{40}Ar_{total}$	Age ($\times 10^6$y)
Rouse-1 Total Rock	1.622 1.620	0.51293	0.426	1.82 ± 0.04

*Denotes radiogenic ^{40}Ar.
Errors are 1 standard deviation based on analytical uncertainties.
Constants used: $^{40}K/K = 1.167 \times 10^{-4}$ mol./mol.
$\lambda_\beta = 4.962 \times 10^{-10}$ y^{-1}
$\lambda_\epsilon = 0.581$ 10^{-10}y^{-1}

for the present we must accept the single date. The result, provided by AMDEL laboratories, is 1.82 ± 0.04 million years. Analytical details are shown in Table 1.

The Plio-Pleistocene boundary was for a long time thought to be at 1.8 million years (e.g. Hays & Berggren 1971, McDougall & Stipp 1968), in which case, the Mount Rouse eruption would fall almost precisely on the boundary. Recent authors (e.g. Harland *et al.* 1982, Veevers 1984) place the boundary at 2.0 million years. Despite this slight change, the Mount Rouse eruption falls sufficently close to the boundary to provide a very convenient marker between the Quaternary and Tertiary flows. Quaternary flows retain topographic features such as stony rises: older flows do not.

The potassium-argon date comes from within the cone, and it might be argued that the cone is much younger than the underlying flows. But in the next section it is argued that the whole volcanic eruption probably took place very quickly, and the age indicated can be regarded as also the age of the underlying lava flows. If this is so there is still a problem of the younger date of McDougall and Gill (1975) listed above. Either their dates are too young, or my 1.82 m.y. date is too old, or there are several different flows. The last possibility seems very unlikely because of the continuity of the very distinctive flows, as seen in the field and on air photographs.

Gill (1957) and Gibbons and Gill (1964) suggested that the basalt of the Hamilton Land-system can be relatively dated at Grange Burn, where basalt overlies fossiliferous marine Kalimnan (Lower Pliocene) on which a palaeosol had developed before the basalt cover was erupted. The basalt was later dated (Turnbull *et al.* 1965) and gave a potassium-argon age of 4.35 ± 0.10 m.y. (4.46 ± 0.10 m.y. on new decay constants). Another date for the Hamilton Land-system basalt was reported by McDougall *et al.* (1966), from Menzel's Quarry, Penshurst, as 3.91 ± 0.15 m.y. (4.01 ± 0.15 m.y. on new decay constants). The Hamilton Land-system basalt therefore had something like 2 to 2.5 million years of weathering before basalt was erupted from Mount Rouse. The Pliocene climate was wetter and warmer than the average Quaternary climate, and the age difference is probably quite enough to explain the very different degrees of weathering.

THE FORMATION OF VERY LONG LAVA FLOWS

The features of the lava flows from Mount Rouse have a bearing on modern ideas about the formation of very long flows, and the nature of the mechanism by which lava flows. Walker (1973) analysed the factors affecting the length of lava flows. He believed that viscosity merely controls the thickness of a lava extrusion, and only indirectly affects the length. The effect of the angle of slope of the underlying land surface, though not negligible, is small in relation to other factors.

This must certainly be so at Mount Rouse, for it flowed over very low gradients. The overall gradient from cone to sea is 1 in 200 (300 m in 60 km), but the more distal portions are considerably flatter.

Walker concluded that the major factor affecting the length of a lava flow is the effusion rate, especially the effusion rate over the first few days of eruption, which is higher than the average rate.

Malin (1980) examined the length, volume and effusion rate of 87 historic Hawaiian lava flows, and found there was little support for a direct relationship between flow length and effusion rate. A relationship between flow length and total volume extruded is statistically more significant. He noted that cross sectional area, effusion rate and volume all play important roles in governing the emplacement of flows and stated "One reason for the observed relationship in Hawaii may be that tube-fed flows, with approximately constant cross-sectional area, advance farther than other types of flows for similar effusion rates and volumes."

Effusion rate may be less important than the continuity of flow in time. If an eruption ceases just long enough for the lava to solidify, lava tubes will be blocked. Lava from a subsequent eruption will then flow *over* the earlier flow, increasing its thickness but not its length. If, on the other hand, an equivalent volume of lava was erupted without interruption, a single very long flow is more likely to be produced, with a lava tube system operating for a longer period.

Flow morphology of lava must be related in some way to its rheological properties. Above the liquidus a silicate melt behaves as a Newtonian fluid (a simple fluid in which the state of stress at any point is proportional to the time rate of strain at that point), but since the classic work of Shaw *et al.* (1968), lava has generally been treated as a Bingham plastic (a non-Newtonian fluid exhibiting a yield stress which must be exceeded before flow starts). Hulme (1974) showed both theoretically and experimentally (using flows of kaolin and water) that flowing Bingham fluids form stationary bodies of fluid at the margins of a flow and have a characteristic thickness for a given slope. In a lava flow, levees of stationary lava might be formed on each side of a mobile flow. This was observed on Mt Etna by Sparks, Pinkerton and Hulme (1976) who wrote "As Hulme predicted, two bordering zones of stationary incandescent lava were formed, termed "initial levees", which determine the width of the channel". It must be remembered that Hulme's hypothesis has limitations, for it is derived for flows in which cooling plays no part.

Fig. 4 (top)—Stereo air photos of Mount Rouse. Note the mound built of stony rise lava on which the final scoria cone was built. Scale 1: 80 000.

Fig. 5 (bottom)—Stereo air photos of the Moorilah Steptoe and the flows which surround it. Note the surface features of the stony rises, and the way lava flows up even minor tributaries. Scale 1:80 000. These photographs are Crown Copyright and have been reproduced by permission of the Director, Division of National Mapping, Department of Resources and Energy, Canberra, Australia.

Very long flows probably cannot be maintained by the "central channel and levee" mechanism. Wilson and Head (1983) wrote "In some cases the upper surface of a flow becomes rigid long before the interior and motion takes place in an enclosed (and hence thermally insulated) tube within the body of the flow." Wadge (1978) had already concluded that "Flow will cease when the chilled crusts develop to some critical thickness." Swanson (1973), however, indicated that lavas within tubes flowed virtually isothermally, cooling at a rate of only about 1°C.km^{-1}. Malin (1980) suggests that such tube-fed flows, if limited only by cooling, could possibly produce flows up to 200 km long, a mechanism quite adequate for the 60 km Mount Rouse flow.

The Mount Rouse flow indicates by its length and its stony-rises morphology that it was a tube fed flow, and was emplaced by mechanisms similar to those described by Wadge, Swanson and Malin. If this is so, it was probably emplaced in a relatively short time, perhaps only days or weeks. The fluidity of the lava flows is further indicated by the apparent ease with which the lava divided into several different flows which re-united further downstream after they had flowed around obstacles. In relation to the lava levee observations of Sparks, Pinkerton and Hulme (1976), it is important in Victoria to distinguish between levees and lateral ridges. Examples of levees can be seen in Victoria where flows leave the northern end of Lake Surprise in the crater of Mount Eccles, and also from Little Mount Eccles. They are essentially formed only close to the point of eruption. Lateral ridges, also called "pressure ridges" in Victoria (Skeats & James, 1937), are found farther down-flow and result from collapse of the flow surface, not from build-up like a levee. In the Mount Rouse flow there are no lava levees, but lateral ridges are occasionally present.

SUMMARY

Mount Rouse erupted about 1.8 million years ago. Eruption of lava flows probably lasted for only a few weeks during which flows covered the 60 km to the sea. Eruption of the Mount Rouse cones and craters was more complicated, and probably lasted somewhat longer. The lava flows were tube-fed, which accounts for the hummocky stony rises topography which is still largely intact. Weathering and erosion are very limited.

For many years the Cainozoic basalts of Victoria have been divided into the Older Basalts and the Newer Basalts. The Newer Basalts can now be divided into two sets, and Mount Rouse marks the beginning of the youngest set (which might be conveniently called the Quaternary Basalts). These include the Girringurrup and younger Land-systems of Downes, Gibbons and Gill. The earlier set of Newer Basalts, including those of the Hamilton Land-system has very much more weathering, although it is not very much older. This might be the result of a considerable climatic change in Victoria before the Quaternary flows were erupted.

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